USE OF SULFUR ON DISPERSED SOILS

C. H. DIEBOLD

SOIL SCIENTIST

GLENN NINER

ASSISTANT NURSERY MANAGER

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INTRODUCTION

In this brief progress report, the literature pertaining to the use of sulfur will not be reviewed. Investigations of the use of sulfur in the Southwest have been confined chiefly to black alkali soils. The possibility that sulfur may be beneficial to certain non-black alkali soils deserves consideration. This facilitating study was undertaken in the sprinkling system plots at the Albuquerque Soil Conservation Service Nursery near Bernalillo, New Mexico to determine if sulfur would correct poor growth and low survival of tree seedlings on a non-black alkali soil.

DESCRIPTION OF AREA AND TREATMENTS

History: The area was subjugated in 1936 from Rio Grande cottonwood bosque. It is divided into borders 50 feet wide and 360 feet long. Before and after the emergence of tree seedlings, the area is sprinkled at least daily. On windy days it is sprinkled several times a day. Good production of tree seedlings was maintained for the first two or three years. Then "hot spots" began to show up at random. In these areas, many seedlings died shortly after emergence. First the tip and then the edges of the cotyledons turned yellowish and within a few hours were brown and dead. Some plants recovered but they were stunted and unusable. Prior to 1945 the following treatments were unsuccessful: manure, green manure crops of sweet clover, cow peas, sudan grass; leaching; and light applications of aluminum sulfate and sulfuric acid.

Soil: The surface soil is medium textured, calcareous, and low in organic matter. It is underlain by loamy fine sand which, at a depth varying from 15 to 25 inches, is underlain by a mottled, heavy loam to clay loam. At depths varying from 30 to 40 inches, layers of sand, sandy loam and sand occur successively above the water table which is encountered at 5.5 to 6.0 feet. This soil is Gila fine sandy loam or soil conservation survey unit 3341.

In general, the surface soils in the "hot spots" (which occupied small areas) were more highly dispersed than in areas of good growth. In border B4 which was considered to have the most "hot spots" in 1944, the average percentage of dispersion of the 5 micron clay from 4 samples was 49% but in a "hot spot" it was 68%. Excluding white alkali areas, good growth of hardwoods occurred when the percentage of dispersion of the medium textured surface soil was less than 35%; growth was poor in soils more than 35% dispersed.

The percentage of water soluble sodium 1/ from the 1:5 salt extract roughly parallels the dispersion values for the surface soils. In general the percentage of sodium exceeded 50% in "hot spots". A study of Table 1 shows

1/ This is calculated by dividing the milligram equivalents of sodium by the sum of the milligram equivalents of calcium, magnesium and sodium determined from the salt extract of one part of soil to five parts of water.

Table 1. Summary of soil analyses a/ from good (g) and "hot spot"(p) areas, Albuquerque Nursery.

Border	Date	Species	Height inches	Depth of soil sample inches	pH 1:1	Bridge salts %	Dispersion %	Water soluble sodium p.p.m.	Water soluble sodium %	Base exchange capacity pounds per acre: Total b/	Base exchange capacity pounds per acre: Sodium	Base exchange capacity pounds per acre: Potassium
				Surface Soil								
B3p	12/45	Black locust	0	0-6	7.8	.25	29	850	47	10.8	1620	740
B3g	12/45	" "	30	0-6	7.8	.17	32	495	47	11.8	870	220
A6p	12/45	Chinese elm	12	0-6	8.1	.24	37	730	65	10.1	1050	1110
A5g	12/45	" "	30	0-6	8.2	.08	25	-	-	10.3	260	370
B4p	3/45	Russian olive	unusable	0-8	8.4	.10	68	298	60			
A11g	12/45	" "	30	0-6	8.2	.07	20	51	14	10.5	260	300
A10g	12/45	" "	24	0-6	8.0	.07	24	83	22	10.3	260	70
A6p	3/45	Chinese elm	unusable	0-11	8.0	.16	76	335	51			
A8g	3/45	" "	6	0-10	7.7	.20	28	411	40			
A2g	3/45	" "	usable	0-6	8.5	.08	34	174	47			
B11Ap	3/45	American elm	6	0-12	8.0	.11	46	287	66			
B11g	3/45	" "	24	0-11	8.0	.13	27	378	61			
				Heaviest Subsoil Layer								
B4p	3/45	Russian olive	unusable	16-26	8.2	.16	45	1200	92			
A6p	3/45	Chinese elm	unusable	21-25	7.8	.30	34	1508	62			
A8p	3/45	" "	6	17-22	7.8	.25	22	882	84			
A2g	3/45	" "	usable	18-22	8.5	.14	24	412	62			
B11Ap	3/45	American elm	6	21-26	7.5	.22	22	361	29			
B11g	3/45	" "	24	11-14	7.8	.29	27	812	52			

a/ The analyses presented in this table and table 2 were made by Austin Erickson, Soil Scientist and Eloise Steele, Physical Science Aid, Soil Conservation Service Soils Laboratory at New Mexico A & M College.

b/ Milligrams per 100 grams.

that the percentage of water soluble sodium is not consistently related to the parts per million of water soluble sodium. On the other hand, the parts per million of water soluble sodium appear to be related to the amount of exchangeable sodium. 2/ The exchangeable sodium in "hot spots" in A6 and B3 varied from 26 to 37% of the total base exchange capacity. 3/ In healthy areas the percentage of exchangeable sodium was less than 6%.

The presence of white alkali or bridge salts in excess of .16% complicates the relation between water soluble sodium, exchangeable sodium and poor growth. On the other hand the percentage of bridge salts was as low as .10 and .11 in some "hot spots." In general bridge salts were appreciably higher in the heaviest subsoil layer than in the surface soil. The texture of the heaviest subsoil layer in the "hot spots" varied from a silt loam to a silty clay loam. In certain "hot spots" the leaching of soluble salts is desirable. Leaching without the use of sulfur in borders A1-5 in 1941 probably accounts for only .14% bridge salts in the subsoil of leached A2 as compared with .25 and .38% in unleached A6 and A8 respectively. On the other hand the percentage of water soluble sodium is identical in both A6 and A2. Since leaching alone was not considered successful, the addition of sulfur appeared to be the logical treatment.

The highest pH recorded on a 1:1 dilution in either the surface soil or subsoil in a "hot spot" was only 8.5. This value occurred on leached A2 as compared with 7.8 on unleached A6. The majority of the pH values were 8.0 - 8.3 with values as low as 7.8 in white alkali affected areas. On a soil paste the highest pH was 8.0. In soil conservation survey mapping these soils would not have been mapped black alkali, nevertheless, the recommended treatment with sulfur and leaching is similar.

Treatment: Based on production records, borders B4, B5, and A9 were considered to be severely, moderately and slightly affected with "hot spots" respectively. Consequently in May, 1945, sulfur was applied to these borders at rates of 3000, 2000, and 1000 pounds per acre except the southernmost border in A9 which received 22,000 pounds per acre. This heavy application was made in order to reduce the pH to 6.5 for growing ponderosa pine. The amount applied was calculated from laboratory studies using sulfuric acid. The sulfur was disked in to a depth of six inches.

In 1945 a green manure crop of sweet clover was grown on the north halves of both B4 and B5. The growth was poor on the former and excellent on the latter. It was turned under in August, 1945. A mulch of weeping lovegrass hay was applied to the middle of A9 in May, 1945, and disked in August, 1945.

2/ Exchangeable sodium is the sodium held on the fine soil particles; it does not go into soil solution unless: (1) The concentration of the solution decreases, (2) It is replaced by a cation such as calcium in calcium sulfate (gypsum).

3/ Total base exchange capacity is the measure of the bases such as calcium, sodium, magnesium, potassium, ammonia and hydrogen which are held on the fine soil particles. These bases may be slowly available but they do not go into soil solution unless: (1) The concentration of the solution decreases, (2) They are replaced by the addition of a soil corrective or fertilizer containing a base.

A combination of sprinkling and flood irrigation was used to keep the soil moist so as to encourage sulfur oxidation. Quick tests during the summer of 1945 indicated an abundance of nitrates except in the 22,000 pound treatment. In March, 1945, border A9 was leached with 6 acre feet of water to determine how much the water table would rise. The water table rose from 69" to 66" during leaching. The average infiltration rate was 0.5 inch per hour with a head of approximately 5 inches. In December, 1945, borders B4, B5 and A9 were leached with approximately 4 acre feet of water.

PROGRESS IN SOIL IMPROVEMENT USING SULFUR

Surface Soil: In December, 1945, 7 months after applying sulfur, the treated borders were leached. Shortly after leaching, soil samples were taken from 6 locations in each treatment and composited. All of these soil samples showed a marked reduction in percentage of water soluble sodium as compared with samples collected in March (Table 2). In border B4 the percentage of water soluble sodium averaged 63% in March, 1945 prior to treatment and was only 30% in December, 1945. The bed treated with 22,000 pounds of sulfur dropped from 35% to 10%. Changes in percentages of dispersion and pH, both paste and 1:1 dilution, were not appreciable.

In August, 1946, all treatments except that involving 22,000 pounds showed marked increases in percentages of water soluble sodium as compared with December, 1945 (Table 2). There was also a marked increase in the sulfates in the 1:5 salt extract, which was correlated with the amount of sulfur applied. This indicates that even under favorable conditions of moisture and high nitrates, an appreciable portion of the sulfur did not oxidize until the second season. The combination of high sulfates and high water soluble sodium indicates that another leaching should be made as soon as possible. Fifteen months after treating with sulfur, both the 1000 and 2000 pound treatments appeared to have had little effect in the percentage of dispersion. In the 3000 pound treatment, dispersion dropped from 49 to 40% and in the 22,000 pound treatment from 27 to 11%. The lighter applications of sulfur had little effect on pH paste. The 3000 pound application, however, reduced the pH on a paste from 7.9 to 7.5 and the 22,000 pound application reduced the pH on a paste from 7.5 to 7.0.

The average exchangeable sodium of the surface six inches was determined in all treatments in both July and December, 1945. There was very little difference between treatments at both times of sampling. The minimum and maximum values were 90 and 170 pounds per acre of exchangeable sodium in the surface six inches. These values were obtained from composite samples which undoubtedly mask much higher values in the "hot spots."

Although the percentages of exchangeable sodium in composite samples were all less than 6% of the total base exchange capacities, seedlings exhibited a uniform marked improvement in growth as compared with untreated areas. It is highly probable that factors other than sodium are involved. The oxidation of sulfur to sulfuric acid probably increases the availability of iron, phosphorus and possibly other elements.

Table 2. Summary of soil analyses from sulfur treatments on the sprinkling system plots, Albuquerque Nursery.

Border	.005 mm. clay %	Texture	Organic Matter %	$CaCO_3$ %	Treatments: Sulfur: lbs./acre	Treatments: Green Manure	Treatments: Hay Mulch	pH Paste		pH 1:1 Soil water ratio			Sodium % water soluble			Sulfates Parts per million				Dispersion %			Bridge Salts %			Base exchange capacity pounds per acre: Total[c]	Sodium	Sodium
	8/46	8/46	3/45	3/45	5/45	8/45	5/45	3/45	8/46	3/45	12/45	8/46	3/45	12/45	8/46	3/45	10/45[b]	12/45	8/46	3/45	12/45	8/46	3/45	12/45	8/46	7/45	7/45	12/45
												Surface Six Inches a/																
A9N	14	sandy loam	0.8	5.3	1000			7.5	7.7	7.7	7.8	8.1	35	18	62	828	700	510	864	28	31	32	.18	.13	.14	9.0	130	130
A9M	12	"	0.8	5.3	1000		Yes	7.5	7.6	7.7	8.1	8.0	35	32	60	828	550	70	1248	28	26	35	.18	.08	.14	9.0	90	130
A9S	14	"	0.8	5.3	22000			7.5	7.0	7.7	7.5	7.2	35	10	10	828	1475	1222	7636	28	27	11	.18	.14	.16	8.5	130	130
B5N	12	"	1.2	5.8	2000	Yes		7.8	7.5	8.1	8.2	—	43	27	35	132	600	58	1392	32	26	29	.11	.07	.14	9.0	170	170
B5S	12	"	1.2	5.8	2000			7.8	7.6	8.1	7.9	—	43	31	64	132	825	247	1056	32	22	34	.11	.11	.15	10.8	170	170
B4N	9	"	1.4	5.0	3000	Yes		7.9	7.5	8.1	7.6	—	63	24	34	461	1250	897	1824	49	30	39	.14	.14	.15	7.8	170	130
B4S	10	"	1.4	5.0	3000			7.9	7.4	8.1	8.0	—	63	37	54	461	1725	95	1440	49	37	42	.14	.09	.15	8.2	170	170
												Heaviest Subsoil Layer																
A9N	22	silt loam	.9	5.3	1000			7.4	7.9	7.8	—	8.2	60	—	72	1158	—	—	624	31		24	.19		.13			
A9M	20	"	.9	5.3	1000		Yes	7.4	7.8	7.8	—	8.3	60	—	62	1158	—	—	768	31		21	.19		.12			
A9S	19	loam	.9	5.3	22000			7.4	7.6	7.8	—	8.0	60	—	41	1158	—	—	960	31		23	.19		.14			
B5N	22	"	1.2	6.5	2000	Yes		7.8	7.9	8.0	—	8.3	82	—	66	889	—	—	816	25		22	.16		.12			
B5S	22	"	1.2	6.5	2000			7.8	7.9	8.0	—	8.3	82	—	42	889	—	—	672	25		18	.16		.13			
B4N	29	clay loam	1.5	5.8	3000	Yes		7.7	7.7	7.9	—	8.1	80	—	58	1384	—	—	864	28		19	.20		.14			
B4S	24	"	1.5	5.8	3000			7.7	7.8	7.9	—	8.1	80	—	63	1384	—	—	960	28		22	.20		.14			

a/ Samples collected in March averaged 10 inches in depth and were collected from 4 locations in each border. The average volume weight of the surface 0-4 inches was 1.41 and field capacity two days after irrigation in October 1945 was 3.9 inches per foot.
b/ Analyses by C. H. Diebold.
c/ Milligrams per 100 grams.

Subsoil: Analyses were made of the heaviest layer in the subsoil prior to treatment and 15 months after treatment. The texture of this layer varies from a heavy loam to a clay loam. The 1000 pound treatment appeared to have little effect on the percentage of water soluble sodium. In all other treatments there were appreciable decreases. For example, in B4, the average percentage of water soluble sodium dropped from 80 to 60 (Table 2.). Leaching reduced the percentages of bridge salts in all treatments approximately one third. However, the more accurate soluble salt determinations indicated that approximately one-half of the salts had been leached out. There was likewise a decrease in total sulfates. All treatments showed a moderate decrease in dispersion, but there was an increase in pH both paste and 1:1, especially in 1000 pound treatment. For the soils studied, the application of one ton or more of sulfur followed by leaching has reduced appreciably the percentage of water soluble sodium and the total salt content.

GROWTH OF TREE SEEDLINGS IN 1946

Analyses of soil samples taken after leaching in December, 1945, indicated that the soil had been improved sufficiently by the treatments to warrant planting. In the spring of 1946, Russian olive was planted in B4; Chinese elm in B5; American elm, desert willow, mulberry, buffalo berry, hackberry and ash in A9, (1000 pound treatment); 12 hardwoods and 2 conifers were planted in the bed receiving 22,000 pounds of sulfur treatment.

During a windy period in late May, Chinese elm and Russian olive seedlings were observed to be dying in both treated and untreated areas. Quick tests for nitrates revealed accumulations five times higher in the dying Chinese elm seedlings than in healthy seedlings (Table 3). The nitrate content of the surface soil was also higher in the "hot spots". Similar data were obtained in "hot spots" planted to black locust. Although the percentage of water soluble sodium in the "hot spots" may be high enough to cause injury, leaf analyses of dying Chinese elm seedlings showed only 0.55% sodium and 0.47% chlorides on June 18, 1945. The principal cause of the high mortality of seedlings appears to be high accumulations of nitrates in the surface inch which are taken up in toxic quantities on windy days by the seedlings.

Table 3.--Comparison of Nitrates and Ammonia in Seedlings and Surface Soils from Good and Poor Areas.

Border	Date	Species	Nitrates (P.P.M. as N) Healthy leaves	Soil (0-2")	Dying leaves	Soil (0-2")	Ammonia (P.P.M. as N) Healthy leaves	Soil (0-2")	Dying leaves	Soil (0-2")
B5	5/27/46	Chinese elm	140	7	800	22	40	2	40	4
B9	6/14/46	Black Locust	300	2	600	7	20	4	60	2
A9S[a]	7/8/46	" "		3		18		2		22

a. Analyses from this border are for the 0-1" depth.

The "hot spots" are characterized by soils more highly dispersed than the healthy areas. Such areas are believed to have a higher water holding capacity, and consequently the nitrates are not leached by light sprinklings.

On the other hand, conditions for subbing are more favorable in the "hot spots" and subsequently the nitrate content of the surface inch often exceeds 15 p.p.m. In 1946 fewer areas were affected by "hot spots" in the sulfur treated borders than in preceding years. This is attributed to the reduction in dispersion. Whenever high concentrations of nitrates were found, prolonged sprinkling was immediately carried out to leach down the nitrates. The combination of sulfur plus heavy sprinkling of spots in the process of reclamation has greatly reduced tree seedling mortality.

The growth of both Russian olive and Chinese elm in the sulfur treated borders was uniformly more vigorous than that in companion untreated borders. On August 6, Russian olive seedlings were 27 inches high in treated B4 (figure 1) and 15 inches high in untreated A4. The minimum requirements for usable Russian olive seedlings are that the top shall be 18 inches long and the ground line diameter shall be one fourth inch. In 1944, B4 produced only 5500 usable seedlings whereas A4 produced 15,000 usable seedlings. In contrast in 1946, B4 and A4 produced at the rate of 28,800 and 20,000 seedlings respectively. The use of sulfur combined with leaching increased five fold the number of usable Russian olive seedlings in B4.

There appeared to be little difference in the growth of Russian olive between the areas which had a cover crop of sweet clover turned under in 1945, and fallow areas. Similar observations were made in Chinese elm. In sulfur treated border A9, usable 1-0 American elm were produced for the first time at the nursery (figure 2). It had previously taken two years to produce usable American elm. The black locust in A9 was healthy and made consistently good growth during July and August, whereas, black locust in untreated B9 was chlorotic and made poor growth until late August when most plants recovered. Good growth of desert willow, mulberry, hackberry and ash were obtained in the treated areas.

In the bed treated with 22,000 pounds sulfur, good growth of all hardwood was obtained except in two "hot spots." Ponderosa pine and Arizona cypress also grew well. Caragana grew vigorously in this bed whereas in border B2 a large majority of the 2-0 stock was chlorotic and was affected by a physiological break down of the roots. J. L. Mielke and L. S. Gill of the Bureau of Plant Industry concluded that neither disease nor the soil fauna were primarily responsible.

CONCLUSIONS

1. Sulfur reduced the mortality of tree seedlings in "hot spots" owing to reduction in dispersion, thus aiding the downward movement of nitrates. In dispersed areas dying seedlings had a high, toxic, concentration of nitrates.

2. Sulfur increased the growth of 15 hardwoods and two conifers in both "hot spots" and unaffected areas. The number of usable Russian olive seedlings was increased five fold in border B4. The percentage of water soluble sodium was reduced appreciably by the use of sulfur. Increased growth may also be due to increased availability of other elements.

Figure 1. Russian olive 27" high on border B 4. August 1946. This area received 3,000 pounds of sulphur per acre May 1945.

Figure 2. Excellent 1-0 American elm on right side of border A 9. November 1946. Treatment 1,000 pounds sulphur per acre May 1945.